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In situ and potential CO_2 evolution from a Fluventic Ustochrept in southcentral Texas as affected by tillage and cropping intensity

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Abstract

Quality of agricultural soils is largely a function of soil organic matter. Tillage and crop management impact soil organic matter dynamics by modification of the soil environment and quantity and quality of C input. We investigated changes in pools and fluxes of soil organic C (SOC) during the ninth and tenth year of cropping with various intensities under conventional disk-and-bed tillage (CT) and no tillage (NT). Soil organic C to a depth of 0.2 m increased with cropping intensity as a result of greater C input and was 10% to 30% greater under NT than under CT. Sequestration of crop-derived C input into SOC was 22±2% under NT and 9±4% under CT (mean of cropping intensities ± standard deviation of cropping systems). Greater sequestration of SOC under NT was due to a lower rate of in situ soil CO_2 evolution than under CT (0.22±0.03 vs. 0.27±0.06 g CO_2–C g^{-1} SOC yr^{-1}). Despite a similar labile pool of SOC under NT than under CT (1.1±0.1 vs. 1.0±0.1 g mineralizable C kg^{-1} SOC d^{-1}), the ratio of in situ to potential CO_2 evolution was less under NT (0.56±0.03) than under CT (0.73±0.08), suggesting strong environmental controls on SOC turnover, such as temperature, moisture, and residue placement. Both increased C sequestration and a greater labile SOC pool were achieved in this low-SOC soil using NT and high-intensity cropping.

Keywords: Carbon dioxide; Carbon mineralization; Carbon sequestration; No tillage; Soil microbial biomass; Soil organic carbon; Soil organic matter

1. Introduction

Knowledge of soil organic matter changes with the adoption of long-term crop and residue management strategies is urgently needed to understand and predict the effects of specific components of agroecosystems on biogeochemical cycling of C and N. Carbon and N cycles are important in controlling (i) nutrient availability to plants, (ii) gas fluxes to the atmosphere, (iii) risks to water quality, and (iv) soil tilth as a result of the interaction between biological activity and soil physical and chemical properties.

Changes in soil organic C (SOC) can be viewed as the balance between C inputs and outputs. Carbon inputs to soil are from crop residues, roots, rhizodeposits, and organic amendments. Intensifying cropping to utilize more of the available growing periods may be one way of increasing C inputs in order to increase SOC, especially in the southeastern USA

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where abundant precipitation and mild temperature occur during winter (Bruce and Langdale, 1997). Carbon outputs from soil are primarily from decomposition of SOC and crop and organic inputs and from sediment loss where erosion is a factor. The rate of decomposition of a specific organic material is controlled largely by environmental conditions (i.e., temperature and moisture) (Parr and Papendick, 1978). However, the rate of decomposition can also be altered by the composition of the material (e.g., nitrogen, lignin, polyphenolic concentrations) (Douglas et al., 1980; Palm and Sanchez, 1991) and the placement of the material (e.g., surface or buried) (Douglas et al., 1980; Ghidey and Alberts, 1993), which modifies the temperature and moisture variables. We evaluated the effect of 9 yr of continuous management (i.e., a factorial arrangement of two levels of tillage and five levels of cropping intensity) on SOC, soil microbial biomass C (SMBC), potential C mineralization, and in situ soil CO_2 evolution.

2. Materials and methods

A long-term field experiment was initiated in 1982 in the Brazos River floodplain in southcentral Texas (30°32′N, 96°26′W). Mean (50 yr) annual air temperature is 20°C and rainfall is 978 mm (Fig. 1). The soil was a Weswood silty clay loam (fine, mixed, thermic Fluventic Ustochrept) with a pH of 8.2 (1:2, soil:water) and an average of 35% clay, 52% silt, and 9% $CaCO_3$ equivalence in the 0–0.2 m depth. Five crop sequences were established (Table 1) under conventional and no tillage. Conventional tillage was disking (100–150 mm depth) and bedding in sorghum [*Sorghum bicolor* (L.) Moench] and soybean [*Glycine max* (L.) Merr.] and disking only in wheat (*Triticum aestivum* L.). Details of tillage and crop management were reported in Franzluebbers et al. (1995b, c). Plots measured 4×12.2 m^2 and were replicated four times. An adjacent location that had been converted to bermudagrass [*Cynodon dactylon* (L.) Pers.] pasture at least 35 yr previously and grazed regularly was also sampled.

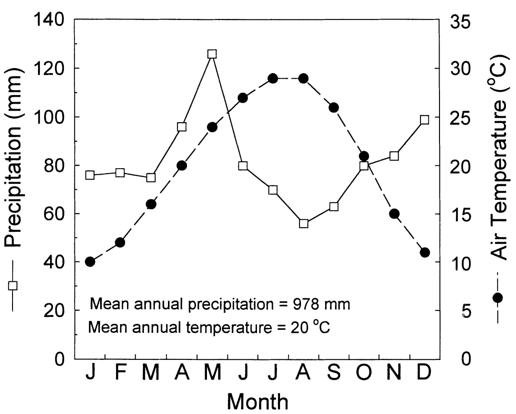

Fig. 1. Mean (50 yr) monthly precipitation and air temperature at College Station, Texas.

Sampling for SOC, SMBC, potential C mineralization, and in situ soil CO_2 evolution was carried out during a 2 yr period from July 1991 to June 1993 and described previously (Franzluebbers et al., 1995b, c; 1996a, b). Brief descriptions of the methods follow for samples collected to a depth of 0.2 m. Soil organic C was determined from samples collected at 12 regular time intervals during the 2 yr period using H_2SO_4/$K_2Cr_2O_7$ at 150°C for 30 min and titration with $FeSO_4$ (Nelson and Sommers, 1982). Soil microbial biomass C was determined at 57 sampling times using $CHCl_3$ fumigation of dried (60°C), pre-incubated soil [7 days, 0.55 water-filled pore space (WFPS), 25°C] and measuring the CO_2–C evolved during 10 days assuming k_C=0.41 (Voroney and Paul, 1984). Potential C mineralization was determined from 57 samples using the rate of CO_2–C evolved from previously dried soil during 7 to 18 days of incubation at 0.55 WFPS and 25°C. In situ soil CO_2 evolution was determined 57 times using a static chamber (0.018 m^2) with alkali absorption during the nighttime only. Soil samples for SOC, SMBC, and potential C mineralization were collected from under the static chamber following chamber removal.

Carbon input was estimated from annual grain yields using grain:stover relationships developed from data during 1991 to 1993 (Franzluebbers et al., 1995a). Crop residue and grain were assumed to contain 42% C. Root-derived C input was assumed to represent 42% of total net C fixed (Whipps, 1990), although differences in this proportion may exist among crops and cultivars.

Relative environmental conditions during the 57 sampling times were indexed by a single value derived from the multiplication of a soil water component and a temperature component. The water component was the fraction of WFPS to a depth of 0.2 m (ranging from 0.25 to 0.95). The temperature component was determined from a nonlinear function that assumed a doubling of activity for every 10°C change in temperature [$2^{((°C-25)/10)}$, (ranging from 0.21 to 1.51)]. Regression was used to estimate the influence of cropping intensity on soil properties using SAS (SAS Institute, 1990).

3. Results and discussion

Total C input (above- and below-ground) increased 42 to 46 g m^{-2} yr^{-1} for each additional month of cropping under both tillage regimes (Fig. 2). Total C input tended to be higher under CT than under NT, averaging 32±32 g m^{-2} yr^{-1} more (mean of cropping intensities ± standard deviation of cropping systems). Cropping intensity, therefore, had a greater impact on C input than tillage regime, despite decreasing N fertilizer input with increasing cropping intensity (Table 1). High-cropping intensity systems made better use of environmental conditions by producing biomass throughout the year. Higher-cropping intensity systems may increase risk of a particular crop failure, but with extended time will likely capture more opportunities for greater potential return than single-crop systems, as indicated from the observed C input during 10 yr.

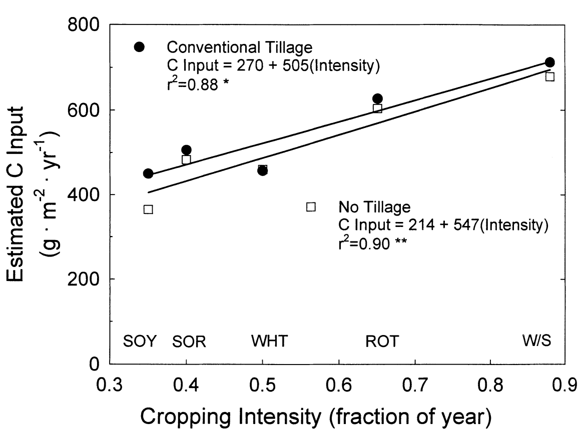

Fig. 2. Estimated total C input (above- and below-ground) to the soil as affected by cropping intensity and tillage regime. (* and ** indicate significance at $P \leq 0.1$ and $P \leq 0.01$, respectively. Cropping intensities are defined in Table 1.)

Table 1
Crop sequence characteristics for long-term experiment in south-central Texas

Crop sequence	Intensity (fraction of year)	Crops (no. yr^{-1})	N fertilizer (g N m^{-2} yr^{-1})
Soybean (SOY)	0.35	1	0
Sorghum (SOR)	0.4	1	13.5
Wheat (WHT)	0.5	1	10.2
Sorghum–wheat/soybean (ROT)	0.67	1.5	4.0
Wheat/soybean (W/S)	0.88	2	3.4

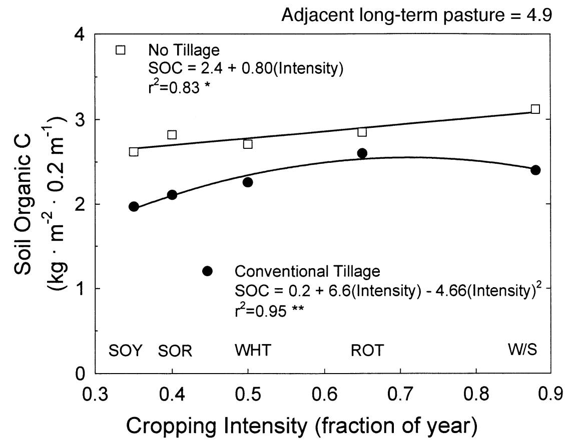

Fig. 3. Standing stock of soil organic C to a depth of 0.2 m as affected by cropping intensity and tillage regime. (* and ** indicate significance at $P \leq 0.1$ and $P \leq 0.01$, respectively. Cropping intensities are defined in Table 1.)

Soil organic C to a depth of 0.2 m in a long-term bermudagrass pasture was 4.94 kg m^{-2}, which agrees very well with the localized prediction of SOC in an assessment throughout the Great Plains (Burke et al., 1989). With cultivation, SOC was only 40% to 63% of that under pasture (Fig. 3). Loss of SOC under cultivation compared with pasture was much higher than predicted by Burke et al. (1989). Cropping systems under NT had 0.56±0.20 kg m^{-2} (25±10%) more SOC than under CT at the end of 9 yr of comparison. In addition, by increasing cropping intensity from monoculture soybean to a wheat/soybean double-crop, SOC increased 0.50 kg m^{-2} with NT and 0.43 kg m^{-2} with CT. As an extreme example, converting from a low-intensity cropping system (i.e., monoculture soybean) with CT to a high-intensity cropping system

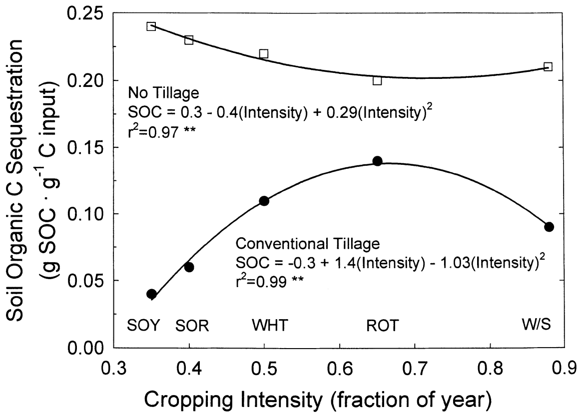

Fig. 4. Portion of total C input sequestered into soil organic C as affected by cropping intensity and tillage regime. (** indicates significance at $P \leq 0.01$. Cropping intensities are defined in Table 1.)

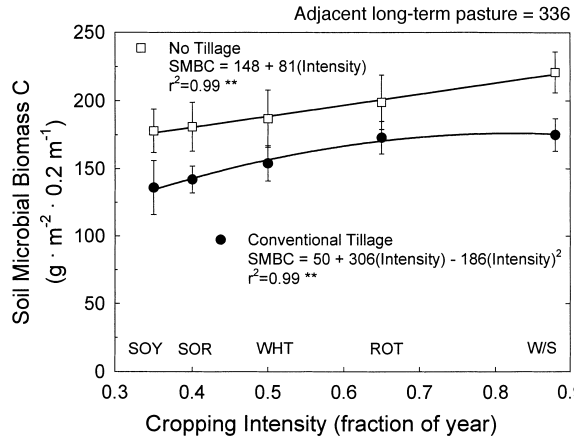

Fig. 5. Standing stock of soil microbial biomass C to a depth of 0.2 m as affected by cropping intensity and tillage regime. (** indicates significance at $P \leq 0.01$. Cropping intensities are defined in Table 1. Error bars are standard error of seasonal variation.)

(i.e., wheat/soybean double-crop) with NT increased SOC to a depth of 0.2 m by 58% at the end of 9 yr. This large response of SOC to management inputs indicates the great potential to sequester C in soils of the mid-south USA, which tend to be low in SOC when cultivated, but are also in an environment with great potential to produce plant biomass throughout the year.

The fraction of total C input that was sequestered as SOC was greater under NT than under CT at all cropping intensities (Fig. 4). Minimal soil disturbance and surface placement of residues with NT restricted contact of residues with the soil matrix, resulting in extreme moisture and temperature fluctuations in and around residues, thereby limiting decomposition (Douglas et al., 1980). Despite lower C input from roots and residues in low-intensity compared with high-intensity cropping systems, the portion of C input that was retained as SOC was similar for all cropping intensities under NT, ranging from 20% to 24% (Fig. 4). This would suggest that the rate of decomposition of residues under NT was proportional to the quantity of residues produced. However under CT, the portion of C input that was retained as SOC increased with increasing cropping intensity, suggesting that high-intensity cropping systems sequestered more C input as SOC and less was mineralized to CO_2, perhaps due to greater soil water extraction with high-intensity cropping, which limited soil water availability for decomposition. Also, residue quality (i.e., N concentration) was the lowest in the wheat and rotated cropping systems (Franzluebbers et al., 1995a), which may have reduced decomposition.

Soil microbial biomass C and potential C mineralization exhibited similar relationships with tillage and cropping intensity as that observed for SOC (Figs. 5 and 6). Soil under NT had 37 ± 8 g m^{-2} (24 ± 6%) more SMBC and 0.79 ± 0.11 g m^{-2} d^{-1} (63 ± 10%) greater potential C mineralization than

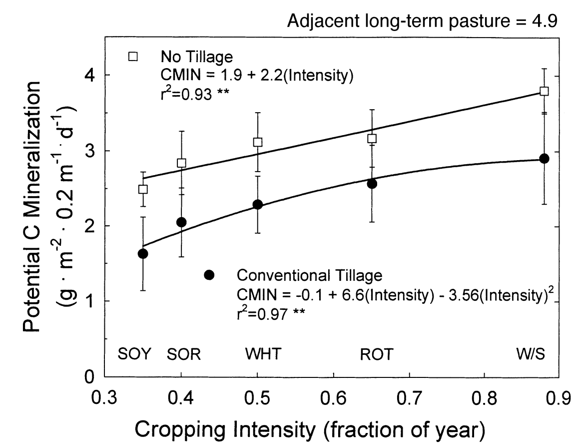

Fig. 6. Standing stock of potential C mineralization to a depth of 0.2 m as affected by cropping intensity and tillage regime. (** indicates significance at $P \leq 0.01$. Cropping intensities are defined in Table 1. Error bars are standard error of seasonal variation.)

under CT. Soil microbial biomass C and potential C mineralization under cultivation were 40% to 66% and 33 to 78% of those under long-term pasture, respectively. As a measure of sensitivity to tillage and cropping intensity treatments, potential C mineralization appeared to be better than SOC and SMBC. However, monthly variation of potential C mineralization ($\pm$17% of yearly mean) was greater than that of SMBC ($\pm$9% of yearly mean), suggesting that caution and/or frequent sampling must be employed when determining management-induced changes in soil C pools. Monthly variation in potential C mineralization was 0.49 ± 0.08 g m^{-2} d^{-1} under CT and 0.34 ± 0.08 g m^{-2} d^{-1} under NT, indicating that crop residue incorporation provided a more seasonally-dynamic distribution, whereby growth and decay of microorganisms from incorporated substrates contributed to temporal variation.

Yearly in situ turnover of SOC was 27$\pm$6% under CT and 22$\pm$3% under NT (Fig. 7). Yearly potential turnover of SOC at 25°C and 0.55 WFPS was 37$\pm$5% under CT and 40$\pm$4% under NT. Adjusting the estimate of potential turnover of SOC for a lower observed mean yearly in situ soil temperature (17°C) and making no adjustment for moisture since mean annual soil water content was greater than 0.55 WFPS under both tillage regimes (Franzluebbers et al., 1995b, c), yielded annual estimates of 21% and 23% turnover for CT and NT, respectively. These adjusted values were similar to the actual in situ estimates of SOC turnover. Estimation of in situ turnover of SOC included root plus microbial respiration. Estimation of potential turnover of SOC excluded root respiration, although the soil was disturbed (dried, sieved, and rewetted), which may have enhanced CO_2 loss, especially under NT. The higher observed estimate compared with the calculated estimate of SOC turnover suggests that root respiration was a significant contribution to soil CO_2 evolution (Whipps, 1990).

In situ soil CO_2 evolution during the ninth and tenth year averaged 1.2$\pm$0.2 g CO_2–C g^{-1} C input, further indicating rapid turnover of plant biomass production. The high mean rate of in situ CO_2 evolution suggests (i) all of the annual C input plus additional SOC was respired in a year, (ii) root respiration was approximately 20% of total C output and was not a part of C input estimates, and/or (iii) estimates of below-ground C input need to be better quantified to account for production of highly-labile rhizodeposition products from root turnover. For example, if 49% instead of 42% of net fixed C was partitioned below-ground, then in situ soil CO_2 evolution would have been 1.0$\pm$0.2 g CO_2–C g^{-1} C input. If only 35% of net fixed C were partitioned below-ground, then in situ soil CO_2 evolution would have been 1.4$\pm$0.2 g CO_2–C g^{-1} C input.

On a monthly basis, in situ soil CO_2 evolution was related to environmental conditions during low plant-activity periods (Fig. 8), but was significantly under-predicted during growing periods based on environ-

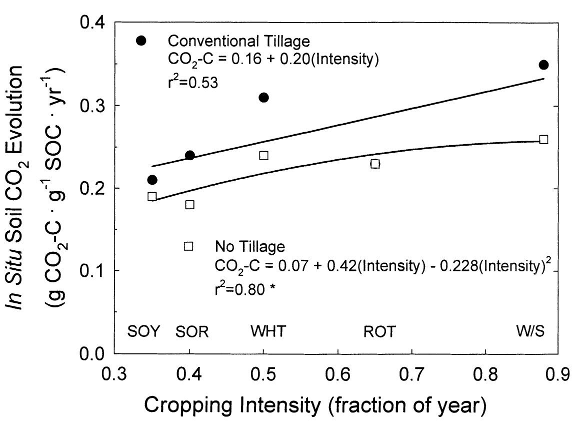

Fig. 7. *In situ* turnover rate of soil organic C to a depth of 0.2 m as affected by cropping intensity and tillage regime. (* indicates significance at $P\leq0.1$. Cropping intensities are defined in Table 1.)

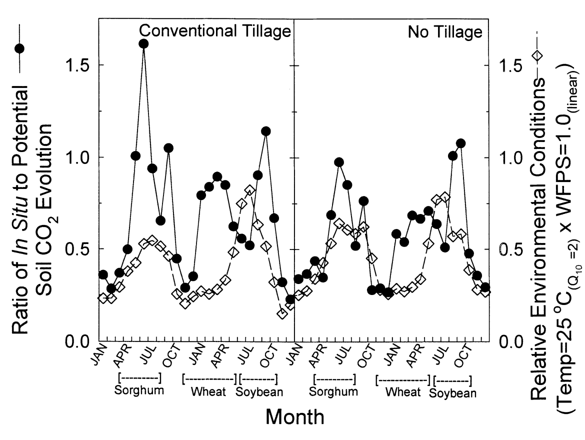

Fig. 8. Seasonal dynamics of the ratio of in situ to potential soil CO_2 evolution and relative environmental conditions under conventional and no tillage in a sorghum-wheat/soybean rotation.

mental conditions alone due to increased contributions from rhizosphere and root respiration. Separation of root respiration from rhizo-microbial respiration has been limited by methodological difficulties, but several studies have indicated that rhizo-microbial respiration is the dominant source. Cheng et al. (1993) found that 60% of soil CO_2 evolution was due to rhizo-microbial respiration during the growth of wheat. Helal and Sauerbeck (1991) observed values of 76% and 84% during growth of bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.), respectively.

4. Summary and conclusions

Soil organic C to a depth of 0.2 m was 25±10% greater with NT compared with CT at nine years, but still only 57±4% of soil under pasture. In situ soil CO_2 evolution under NT was 5±12% greater than under CT on an absolute basis, but 17±11% lower per unit of SOC. Surface placement with NT spared crop residues from rapid decomposition in this warm, moist environment. Increased C input with increasing cropping intensity led to a greater fraction of C input retained as SOC with CT. Our data suggests that the rate of SOC turnover at this location was very rapid due to the warm, moist climate that was conducive for soil microbial activity and therefore indicates the need for reduced tillage and high-intensity cropping to achieve a suitable level of SOC for maintaining soil tilth and quality.

References

Bruce, R.R., Langdale, G.W., 1997. Soil carbon level dependence upon crop culture variables in a thermic-udic region. In: Paul, E.A., Paustian, K., Elliott, E.T., Cole C.V. (Eds.), Soil Organic Matter in Temperate Agroecosystems: Long-Term Experiments in North America, CRC Press, Boca Raton, FL pp. 247–261.

Burke, I.C., Yonker, C.M., Parton, W.J., Cole, C.V., Flach, K., Schimel, D.S., 1989. Texture, climate, and cultivation effects on soil organic matter content in US grassland soils. Soil Sci. Soc. Am. J. 53, 800–805.

Cheng, W., Coleman, D.C., Carroll, C.R., Hoffman, C.A., 1993. In situ measurement of root respiration and soluble C concentrations in the rhizosphere. Soil Biol. Biochem. 25, 1189–1196.

Douglas, C.L., Jr., Allmaras, R.R., Rasmussen, P.E., Ramig, R.E., Roager, N.C., Jr., 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Sci. Soc. Am. J. 44, 833–837.

Franzluebbers, A.J., Hons, F.M., Saladino, V.A., Sorghum, 1995a. Wheat and soybean production as affected by long-term tillage, crop sequence and N fertilization. Plant Soil 173, 55–65.

Franzluebbers, A.J., Hons, F.M., Zuberer, D.A., 1995b. Tillage and crop effects on seasonal dynamics of soil CO_2 evolution, water content, temperature, and bulk density. Appl. Soil Ecology 2, 95–109.

Franzluebbers, A.J., Hons, F.M., Zuberer, D.A., 1995c. Tillage-induced seasonal changes in soil physical properties affecting soil CO_2 evolution under intensive cropping. Soil Tillage Res. 34, 41–60.

Franzluebbers, A.J., Hons, F.M., Zuberer, D.A., 1996a. Seasonal dynamics of active soil carbon and nitrogen pools under intensive cropping in conventional and no tillage. Z. Pflanzenernähr. Bodenk. 159, 343–349.

Franzluebbers, A.J., Hons, F.M., Zuberer, D.A., 1996b. Tillage and crop effects on seasonal soil carbon and nitrogen dynamics. Soil Sci. Soc. Am. J. 59, 1618–1624.

Ghidey, F., Alberts, E.E., 1993. Residue type and placement effects on decomposition: field study and model evaluation. Transactions of the ASAE 36, 1611–1617.

Helal, H.M., Sauerbeck, D., 1991. Short term determination of the actual respiration rate of intact plant roots. In: Michael, B.L., Persson, H. (Eds.), Plant Roots and Their Environment, Elsevier, Amsterdam, pp. 88–92.

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon, and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, Part 2, 2nd ed. Agronomy Monograph 9, Am. Soc. Agron., Soil Sci. Soc. Am., Madison, WI. pp. 539–594.

Palm, C.A., Sanchez, P.A., 1991. Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. Soil Biol. Biochem. 23, 83–88.

Parr, J.F., Papendick, R.I., 1978. Factors affecting the decomposition of crop residues by microorganisms. In: Oshwald, W.R. (Ed.), Crop Residue Management Systems. Am. Soc. Agron. Spec. Publ. 31, Am. Soc. Agron., Madison, WI, pp. 101–129.

SAS Institute., 1990. SAS User's Guide: Statistics, Version 6 ed. Cary, NC, 956 pp.

Voroney, R.P., Paul, E.A., 1984. Determination of k_C and k_N in situ for calibration of the fumigation-incubation method. Soil Biol. Biochem. 16, 9–14.

Whipps, J.M., 1990. Carbon economy. In: Lynch, J.M. (Ed.), The Rhizosphere. Wiley, New York, pp. 59–97.